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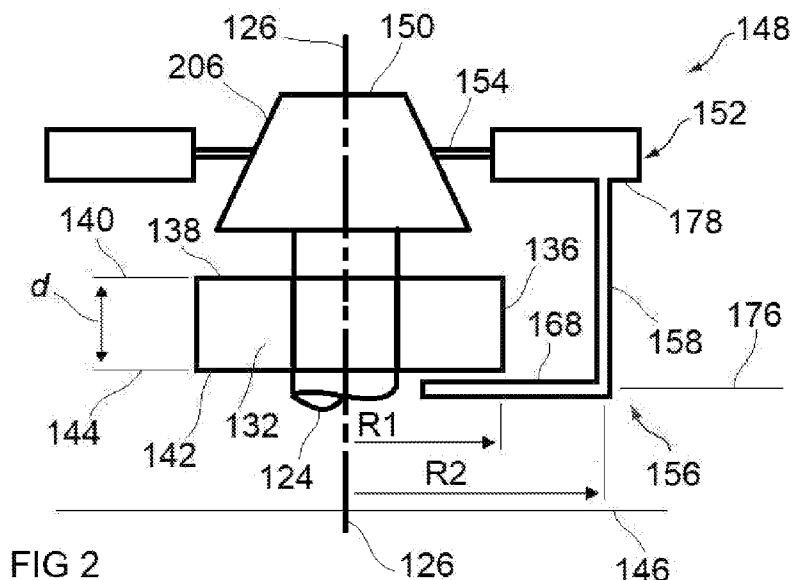
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(57) Abstract: A pump includes a pumping mechanism a rotor shaft (124) having an axis of rotation (126). The rotor shaft is supported for rotation by a plurality of bearings including a rolling bearing (132) having an outer periphery (136). The pump also includes a lubricant supply system (148) and a lubricant transfer device (150) provided on the rotor shaft to transfer lubricant from the lubricant supply system to the rolling bearing. The lubricant supply system includes a lubricant reservoir (152) and a lubricant return system (156) by which lubricant that exits the rolling bearing is returned to the lubricant reservoir. The lubricant return system includes a lubricant return passage (158) that has an upstream end (174) and extends from the upstream end past the outer periphery (136) of the rolling bearing and is configured such that, in use, lubricant is able to move in an upwards direction in the lubricant return passage by capillary action.

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PUMP BEARING LUBRICANT SUPPLY SYSTEMS

Field of the Invention

- 5 The invention relates to pump bearing lubricant supply systems and particularly, but not exclusively, to the lubrication of bearings in a turbomolecular pump.

Background to the Invention

- 10 Many pumps comprise an impeller in the form of a rotor mounted on a rotor shaft and a stator surrounding the rotor. The rotor shaft is supported by a bearing arrangement that may comprise two bearings located at, or intermediate, respective ends of the shaft. One or both of these bearings may be a rolling bearing. The upper bearing may be in the form of a magnetic bearing and the lower bearing a rolling bearing. This arrangement may be used in vacuum pumps such as, for example, turbomolecular vacuum pumps.

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- A typical rolling bearing comprises an inner race fixed relative to the rotor shaft, an outer race fixed relative to a support structure, for example a pump housing, and a plurality of rolling elements located between the races to facilitate relative rotation of the inner race and the outer race. To prevent mutual contact between the rolling elements they are often
20 guided and evenly spaced by a cage. Adequate lubrication is essential to ensure accurate and reliable operation of rolling bearings. The main purpose of the lubricant is to establish a load-carrying film separating the bearing components in rolling and sliding contact in order to minimise friction and wear. Other purposes include the prevention of oxidation or corrosion of the bearing components, the formation of a barrier to contaminants and the
25 transfer of heat away from the bearing components. The lubricant is generally in the form of either oil or grease (a mixture of oil and a thickening agent).

- Pumps using oil-lubricated bearings require an oil feed system to feed oil between the contact areas of the bearing to enable the oil to cool and lubricate the bearing. This
30 facilitates operation at high rotational speeds. Turbomolecular vacuum pumps have traditionally used a wicking system for supplying oil to a rolling bearing. In such a system, a felt wick supplied by an oil reservoir feeds oil to a conical "oil feed" nut mounted on the shaft. The oil reservoir may comprise two stacks comprised of layers of felt that lay against

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respective major surfaces of the felt wick so that the felt wick is sandwiched between the two stacks. In use, when the shaft is rotated, oil travels upwardly along the conical surface of the nut to the bearing. The oil then passes through the bearing and is returned to the reservoir under the influence of gravity. Return of lubricant to the reservoir may be a
5 problem if the pump is not designed, or is orientated, such that the bearing is above the reservoir, particularly in a so-called inverted pump arrangement in which the reservoir is above the bearing so that the returning oil has to flow upwardly against gravity.

US2008/0112660 discloses a turbomolecular pump in which the rotor shaft is supported by
10 an upper bearing and a lower bearing. The rotor blades, stator and pump motor are disposed at positions intermediate the two bearings. The rotor blades and stator are positioned relatively closer to the upper bearing and the pump motor is disposed below and relatively closer to the lower bearing. The upper bearing may be a magnetic bearing and the lower bearing is a rolling bearing. The rolling bearing is a part of a module that comprises a
15 holder, which is push-fitted into a mating recess provided in the pump housing to accurately locate the rolling bearing with respect to the rotor shaft. The rolling bearing is supplied with oil from a lubricant reservoir via an oil feed nut. The oil feed nut is fitted on the rotor shaft. The lubricant reservoir is made of an absorbent material such as felt and is mounted in the holder along with the rolling bearing. The lubricant reservoir includes an extension
20 rod, also made of the absorbent material, that extends from the reservoir past the outer periphery of the rolling bearing. The extension rod extends parallel to the rotor shaft and has an upstream end positioned above and to one side of the rolling bearing. A radial delivery means is disposed above or adjacent the upper end of the rolling bearing to deliver oil that has passed through the rolling bearing to the extension rod. The extension rod must
25 firmly engage the main body of the lubricant reservoir to ensure oil transfer between the two can take place. The radial delivery means comprises a slot formed between an upper end of the holder and the pump housing or between the two halves of a two-piece holder. The slot is configured to cause the oil it receives from the rolling bearing to flow radially outwardly of the rotor shaft into the upstream end of the extension rod. By means of
30 suitable spacers the slot is dimensioned such that oil flows along the slot to the extension rod under the influence of capillary forces. The returning oil then flows back past the

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rolling bearing to the main body of the lubricant reservoir within the absorbent extension rod.

Summary of the Invention

5 The invention provides a pump as specified in claim 1.

The invention also includes a method of manufacturing a pump housing as specified in claim 15.

10 The invention also includes pump comprising:

a pump housing;

a pumping mechanism disposed in said pump housing, said pumping mechanism comprising a rotor shaft having an axis of rotation;

15 a plurality of bearings supporting said rotor shaft for rotation relative to said pump housing, said plurality of bearings including a rolling bearing having an outer periphery, a first major side disposed in a first plane that extends transverse to said axis of rotation and a second major side disposed in a second plane that is spaced from said first plane and extends transverse to said axis of rotation;

a lubricant supply system; and

20 a lubricant transfer device provided on said rotor shaft to transfer lubricant from said lubricant supply system to said first major side of said rolling bearing,

wherein said lubricant supply system comprises a lubricant reservoir and a lubricant return system by which lubricant that exits said rolling bearing at said second major side is returned to said lubricant reservoir, and

25 wherein said lubricant return system comprises a lubricant return passage that has an upstream end and extends from said upstream end past said outer periphery and through said first plane and is configured such that, in use, lubricant is able to move in an upwards direction against gravity in said lubricant return passage by capillary action and there is no absorbent wicking material fitted in said lubricant return passage.

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The invention also includes pump comprising:

a pump housing;

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a pumping mechanism disposed in said pump housing, said pumping mechanism comprising a rotor shaft having an axis of rotation;

a plurality of bearings supporting said rotor shaft for rotation relative to said pump housing, said plurality of bearings including a rolling bearing having an outer periphery, a
5 first major side disposed in a first plane that extends transverse to said axis of rotation and a second major side disposed in a second plane that is spaced from said first plane and extends transverse to said axis of rotation;

a lubricant supply system; and

a lubricant transfer device provided on said rotor shaft to transfer lubricant from
10 said lubricant supply system to said first major side of said rolling bearing,

wherein said lubricant supply system comprises a lubricant reservoir and a lubricant return system by which lubricant that exits said rolling bearing at said second major side is returned to said lubricant reservoir, and

wherein said lubricant return system comprises a plurality of lubricant return
15 passages and said passages have respective cross-section areas that are different sizes whereby, in use, as the respective cross-section areas change due to thermal expansion and contraction as temperature conditions in said pump change, different said lubricant return passages become active to move said lubricant that exits said rolling bearing in an upwards direction by capillary action.

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The invention also includes a pump comprising:

a pump housing;

a pumping mechanism disposed in said pump housing, said pumping mechanism comprising a rotor shaft having an axis of rotation;

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a plurality of bearings supporting said rotor shaft for rotation relative to said pump housing, said plurality of bearings including a rolling bearing having an outer periphery, a first major side disposed in a first plane that extends transverse to said axis of rotation and a second major side disposed in a second plane that is spaced from said first plane and extends transverse to said axis of rotation;

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a lubricant supply system; and

a lubricant transfer device provided on said rotor shaft to transfer lubricant from said lubricant supply system to said first major side of said rolling bearing,

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wherein said lubricant supply system comprises a lubricant reservoir and a lubricant return system by which lubricant that exits said rolling bearing at said second major side is returned to said lubricant reservoir,

5 wherein said lubricant return system comprises a lubricant return passage that has an upstream end and is configured such that, in use, lubricant is able to move in an upwards direction in said lubricant return passage by capillary action, and

10 wherein i) said pump housing or ii) a holder fitted into said pump housing that holds at least one of said lubricant reservoir comprises a first portion that is non-porous and at least one second portion having a structure that is porous and said at least one second portion defines at least a portion of said lubricant return passage.

Brief Description of the Drawings

In the following disclosure, reference will be made to the drawings, in which:

15 Figure 1 is a schematic illustration of a turbomolecular pump in an inverted condition;

Figure 2 is a schematic illustration of a lubricant supply system for a rolling bearing of the turbomolecular pump of Figure 1;

20 Figure 3 is a cross section view showing aspects of a lubrication supply system according to Figure 2;

Figure 4 is a cross section view showing aspects of another lubrication supply system according to Figure 2;

25

Figure 5 shows an internal structure for a lubricant return passage that may be a used in an

Detailed Description

30 Referring to Figure 1, a turbomolecular pump 110 comprises a pump housing, or casing, 112, a pumping mechanism 114 disposed in the pump housing, an inlet 116 and an outlet 118. The pump housing 112 provides an enclosed space in which the pumping mechanism 114 is housed and may include internal walls or partitions that divide the enclosed space

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into compartments or provide mountings for pump components. The pump housing 112 may comprise multiple parts that are permanently or semi permanently connected to one another. The pumping mechanism 114 may comprise a turbomolecular pumping mechanism comprising a plurality of rotor blades 120 disposed in interleaving relationship with a plurality of stator discs 122. The rotor blades 120 may be mounted on, or integral
5 with, a rotor shaft 124 that has a longitudinal axis (axis of rotation) 126. The rotor shaft 124 is driven to rotate about the axis of rotation 126 by a motor 128. The pumping mechanism 114 may additionally comprise a molecular drag pumping mechanism 130, which may be a Gaede mechanism, a Holweck mechanism or a Siegbahn mechanism.
10 There may be additional, or alternative, mechanisms downstream of the molecular drag pumping mechanism such as an aerodynamic pumping mechanism comprising a regenerative mechanism.

Still referring to Figure 1, the rotor shaft 124 is supported by a plurality of bearings 132,
15 134. The plurality of bearings may comprise two bearings 132, 134 positioned at, or adjacent, respective ends of the rotor shaft 124 as shown, although, this is not essential and in other examples one or both bearings may be disposed intermediate the ends of the rotor shaft. In still further examples, the rotor shaft 124 may be supported by two bearings located near the base of the shaft with the rotor blades 120 cantilevered. In the example
20 illustrated by Figure 1, a rolling bearing 132 supports a first end portion of the rotor shaft 124 and a magnetic bearing 134 supports a second end portion of the rotor shaft 124. A second rolling bearing may be used as an alternative to the magnetic bearing 134. When a magnetic bearing 134 is used, a back-up rolling bearing (not shown) may optionally be provided.

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Referring to Figure 2, the rolling bearing 132 comprises an outer periphery 136, a first major side 138 that is disposed in a first plane 140 that extends transverse to the axis of rotation 126 and a second major side 142 disposed in a second plane 144 that is spaced from the first plane and extends transverse to the axis of rotation. The outer periphery 136
30 is disposed a first radial distance R1 from the axis of rotation 126. The first and second planes 140, 144 may be disposed perpendicular to the axis of rotation 126 and in parallel spaced apart relation. The distance d between the first and second planes 140, 144 may

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correspond to the height of the rolling bearing 132. As illustrated by the examples shown in Figures 3 and 4, the rolling bearing 132 is provided between the first end portion of the rotor shaft 124 and a bearing holder 145 that is fitted in the housing. The bearing holder 145 defines a seat 146 (Figure 4) for the rolling bearing 132. The seat 146 may be configured to engage and locate the outer periphery 136 and second major side 142 of the rolling bearing 132. In other examples, the seat for the rolling bearing 132 may be defined by a part of the pump housing 112, rather than by a removable holder.

Referring to Figures 1 and 2, with reference to a datum 147 that extends transverse to the longitudinal axis 126 and bisects that axis at a location intermediate the bearings 132, 134, the rolling bearing 132 is disposed above the datum 147 when the turbomolecular pump 110 is in an inverted condition. Although not essential, in the illustrated example, the longitudinal axis 126 is disposed perpendicular to the datum 147 and the rolling bearing 132 is disposed towards the top of the turbomolecular pump 110 and the bearing 134 is towards the bottom of the pump. In this orientation of the turbomolecular pump 110, the rolling bearing 132 may be referred to as the upper bearing and the bearing 134 may be referred to as the lower bearing.

Still referring to Figures 1 and 2, a lubricant supply system 148 is provided to supply lubricant to a lubricant transfer device 150 via which lubricant from the lubricant supply system is transferred to the rolling bearing 132 to cool and lubricate the bearing. The lubricant supply system 148 may comprise a lubricant reservoir 152 and at least one contactor 154 via which lubricant from the lubricant reservoir is supplied to the lubricant transfer device 150. The lubricant supply system 148 may also comprise a lubricant return system 156 by which lubricant that has been supplied to the first major side 138 of the rolling bearing 132 via the lubricant transfer device 150 and exited via the second major side 142 is returned to the lubricant reservoir 152.

As best seen in Figure 3, the lubricant reservoir 152 may comprise two reservoir body portions 152-1, 152-2 and the one or more contactors 154 may take the form of a finger, or fingers, projecting inwardly of the lubricant reservoir to engage the lubricant transfer device 150. The contactor, or contactors, 154 may project from a body member 160 sandwiched

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between first and second reservoir body portions 152-1, 152-2. In use, lubricant from the lubricant reservoir 152 flows to the lubricant transfer device 150 via the one or more contactors 154 and lubricant that has passed through the rolling bearing 132 is returned to the lubricant reservoir via the lubricant return system 156. For the sake of simplicity, in the description of Figures 1 to 3 that follows, reference will be made to just one contactor 154, although, it is to be understood that this is not to be taken as limiting as two, three or more contactors may be provided.

The lubricant return system 156 may comprise one or more lubricant return passages 158 and lubricant collection channelling 168 configured to receive lubricant that has passed through the rolling bearing 132 and channel it in a lateral direction with respect to the axis of rotation 126 to the one or more lubricant return passages 158. For the sake of simplicity, in the description of Figures 1 to 3 that follows, reference will be made to just one lubricant return passage 158, although, it is to be understood that this is not to be taken as limiting as there may be two or more lubricant return passages 158.

Referring to Figure 3, the lubricant collection channelling 168 has a downstream end 170 and an upstream end 172. The lubricant collection channelling 168 may be configured to conduct lubricant that has passed through the rolling bearing 132 in a generally radially outwards direction from positions adjacent the second major side 142 of the rolling bearing 132 towards an upstream end 174 of the lubricant return passage 158. The upstream end 172 of the lubricant collection channelling 168 may comprise an arcuate channel portion extending at least partially about the rotor shaft 124 and the downstream end 170 may be the free end of a spur channel portion that extends outwardly of the arcuate channel portion. The arcuate channel portion may comprise an annular channel portion and the spur channel portion may project radially outwardly of the annular channel portion. The upstream end 174 of the lubricant return passage 158 may be disposed at or adjacent the downstream end 170 of the lubricant collection channelling 168 to receive and return lubricant from the lubricant collection channelling 168 to the lubricant reservoir 152. Although not essential, the upstream end 174 of the lubricant return passage 158 and downstream end 170 of the lubricant collection channelling 168 may be disposed a second radial distance R2 from the axis of rotation 126 that is greater than the first radial distance R1. The upstream end 174

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of the lubricant return passage 158 may be disposed in a third plane 176 (Figure 2) that extends transverse to the axis of rotation 126 and is spaced apart from the first and second planes 140, 144. The third plane 176 may be disposed parallel to the first and second planes 140, 144 and the second plane 144 may be disposed intermediate the first and third planes.

5 In some examples, an absorbent collector body 177 may be disposed in the collection channel 168.

Referring to Figure 2, the lubricant return passage 158 may extend from the downstream end 170 of the lubricant collection channelling 168 past the outer periphery 136 of the rolling bearing 132 and through the first and second planes 140, 144 to the surface 178 of the lubricant reservoir 152 that is disposed closest to the rolling bearing 132. The lubricant return passage 158 may extend parallel to the axis of rotation 126 of the rotor shaft 124.

10 With respect to the axis of rotation 126, the lubricant return passage 158 may be disposed a radial distance from the axis of rotation 126 that is greater than the first radial distance R1 for at least the part of its length where it is disposed adjacent the outer periphery 136 of the rolling bearing 132. Thus, in some examples, while the portion of the lubricant return passage 158 that extends from the upstream end 174 through the first and second planes 140, 144 is disposed radially outwardly of the outer periphery 136 of the rolling bearing 132 at for example the radius R2, as the lubricant return passage approaches the lubricant reservoir 152, it may converge on the rotor shaft 124.

15 20

The lubricant return passage 158 is configured such that, in use, lubricant from the lubricant collection channelling 168, or where provided, the absorbent collector body 177, is drawn into the upstream end 174 of the lubricant return passage 158 and caused to move upwardly against gravity towards the lubricant reservoir 152 by capillary action. It will be understood that the lubricant return passage 158 is relatively narrow to provide the desired proportions for capillary action to take place without the presence of an absorbent wicking material such as felt and is shown out of proportion in Figure 3 for the purposes of representation.

25 It will also be understood that although in some examples there may be just one lubricant passage 158, as mentioned above, there may be a plurality of lubricant return passages. This may be desirable to provide an adequate flow capacity, to provide for a better distribution of the returning lubricant around the lubricant reservoir 152 by delivering

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returning lubricant to separate spaced apart locations in the reservoir or to provide separate return routes in case a passage should become blocked. In examples in which there are multiple lubricant return passages 158, the lubricant collection channelling 168 may comprise an inner channel portion extending at least partially about the rotor shaft 124 and
5 respective connecting portions extending between the inner channel portion and the respective upstream ends of the lubricant return passages.

The lubricant reservoir 152, at least one contactor 154, body member 160 and absorbent collector body 177 (when provided) may be made of a stable fibrous material or materials
10 that are able to conduct lubricant by a capillary or wicking action. The fibrous material may be natural or synthetic and, in some examples, may be a felt material. The lubricant reservoir 152, at least one contactor 154, body member 160 and collector body 177 (when provided) may be made of the same fibrous material, although in some examples different fibrous materials may be used. Although not essential, one or both reservoir body portions
15 152-1, 152-2 of the lubricant reservoir may comprise a plurality of relatively thin layers of fibrous material stacked one upon another as shown in Figures 3 and 4.

Still referring to Figure 3, the lubricant return system 156 may further comprise a deflector 179 mounted on the rotor shaft 124. The deflector 179 may comprise a drip former 180 to
20 prevent the flow of lubricant along the underside of the deflector (as viewed in Figure 3) towards the rotor shaft 124. As shown, the drip former 180 may comprise a depending annular skirt, although, it may take many other forms such as an annular groove in the underside of the deflector. The deflector 179 may be mounted on the rotor shaft 124 such that the rolling bearing 132 is disposed between the deflector and the lubricant transfer
25 device 150. The positioning of the deflector 179 is such that lubricant that has passed through the rolling bearing 132 may impinge on the deflector. The deflector 179 is configured to deflect lubricant that has passed through the rolling bearing 132 into the lubricant collection channelling 168. The deflector 179 may be seated on a shoulder defined by a reduced diameter section of the rotor shaft 124. The shoulder may be disposed
30 adjacent a bore 186 provided in a partition 188 that separates the pumping mechanism 114 and motor 128 from the rolling bearing 132. The partition 188 may be an integral part of the pump housing 112 or an element fitted into and secured to the housing 112. The

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deflector 179 is configured to shield the bore 186 against the ingress of lubricant that has passed through the rolling bearing 132 and deflect, or divert, the lubricant into the lubricant collection channelling 168. In the illustrated examples the deflector 179 is mounted on the rotor shaft 124. In some examples, a deflector may be provided on rolling bearing, for example on the inner race.

Still referring to Figure 3, the lubricant supply system 148 may comprise a holder 190, 194 to hold the lubricant reservoir 152 and body member 160 in an assembled condition. The holder 190, 194 may comprise a main holder body 190 configured to receive the lubricant reservoir 152 and body member 160 and an extension body 194 that at least partially defines the lubricant return passage 158. The extension body 194 may be integral with the main holder body 190 as shown in Figure 3, or a separate part that is secured to the main holder body or fitted in the pump housing 112 such that it abuts the inner end of the main holder body.

The bearing holder 145 and holder 190, 194 may be received in a recess 200 provided at an end of the pump housing 112. The inner end of the recess 200 may be at least in part be defined by the partition 188. The holder 190, 194 may be held in place in the recess 200 by an end cap 202 that may be secured to the housing 112 by bolts 204, clamps, screws or any other suitable securing mechanism.

As shown in Figure 3, the lubricant transfer device 150 may comprise a hollow frusto-conical body secured to the rotor shaft 124. The lubricant transfer device 150 has a longitudinal axis that is coincident with the longitudinal axis 126 of the rotor shaft 124. The lubricant transfer device 150 has an outer surface 206 that tapers radially outwardly with respect to the longitudinal axis 126 as it approaches the rolling bearing 132. The rotor shaft 124 and lubricant transfer device 150 may be provided with male and female threads respectively to enable the lubricant transfer device to be screwed onto the rotor shaft in the manner of a nut. Alternatively, in some examples, the lubricant transfer device 150 may comprise a sleeve-like construction that is slid onto the rotor shaft 124 and secured to the rotor shaft by means of a nut, bolt, screw or other suitable securing means. In other

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examples, the lubricant transfer device may be a solid body provided with a male thread at one end to screw into a female thread provided in an end of the rotor shaft.

Figure 4 shows an alternative lubrication system for the turbomolecular pump 110.

5 Components that are the same as, or similar to, components shown in Figure 3 will be referenced by the same reference numerals and may not be described in detail again. In the arrangement shown in Figure 3, there is no holder 190, 194 for the lubricant reservoir and body member 160. Instead, these sit in a recess defined in the housing 112.

10 In this example, the lubricant return system 156 comprises a plurality of lubricant return passages 158 and the lubricant collection channelling 168 includes an optional lubricant return reservoir 169 disposed at the downstream end of a lubricant collection channelling 168 adjacent the respective upstream ends 174 of the lubricant return passages 158. Thus, in use of this example, lubricant that has passed through the rolling bearing 132 and exited
15 at the second major side 142 is channelled to the lubricant return reservoir 169 from where it is drawn into one or more of the lubricant return passages 158 and moved upwardly towards the lubricant reservoir 152 by capillary action.

In some examples, the lubricant return passages 158 may have respective cross-section
20 areas sized differently so that, in use, as the respective cross-section areas change due to thermal expansion and contraction caused by changing temperature conditions in the turbomolecular pump 110, different lubricant return passages become active to move the lubricant in an upwards direction by capillary action. Thus, as one or more lubricant return passages 158 becomes inoperative due to expansion or contraction induced by changing
25 thermal conditions in the turbomolecular pump 110, at least one of the lubricant return passages 158 will become, or remain, operative to channel lubricant upwardly by capillary action. While not restricted to lubricant passages having an exactly circular cross-section, in examples in which the lubricant return passages have circular cross-sections, the respective different sized cross-section areas will be the product of different passage
30 diameters. It will be understood that in examples in which there is a plurality of different sized lubricant return passages, it is not essential that all of the lubricant return passages have a different size. For example, in an example with eight lubricant return passages, two

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may have cross-section area size A, two may have cross-section area size B, two may have cross-section area size C and two may have cross-section area size D, where $A > B > C > D$.

5 In at least some examples, the pump housing 112, or at least a part of the pump housing in which the or a lubricant passage is defined may be manufactured with an integral lubricant return passage, or passages, by a generative production process, popularly known as 3D printing or additive manufacturing (AM). Suitable generative production processes may include material extrusion (including fuse deposition modelling (FDM)), binder jetting,
10 powder bed fusion, directed energy deposition and sheet lamination. Of these, powder bed fusion or fuse deposition modelling where the casing is built up leaving an open passage, or passages, through which the returning lubricant can flow or sintered powder to be removed to form the lubricant return passage, or passages, may be particularly suitable. For example, a fuse deposition moulding may use a suitable metal to form the pump casing
15 and an epoxy to define the lubricant return passage, or passages, so that when the structure is heated to fuse the metal powder, the epoxy is melted. This method has the advantage that no metal powder has to be removed to clear the passage or passages. Similarly, in examples in which the, or a, lubricant return passage is provided in a holder fitted in the pump housing 112, the holder may be formed by a generative production process.

20

It will be understood that the lubricant collection channelling may also be formed along with the lubricant return passage in a part, for instance a part of the pump housing, produced by means of a generative production process. It will also be understood that the lubricant collection channelling may include bores and passages extending within the part in which
25 it is defined and it is not limited to open channels.

Referring to Figure 5, it is not essential that the or each lubricant return passage is an open passage; that is a passage that comprises an uninterrupted open, or empty, flow path. A lubricant return passage may be at least partially defined by a portion of the pump housing
30 112 that while not devoid of structure has greater porosity than a surrounding portion of the pump housing sufficient to allow lubricant to flow through it. Thus, as shown in Figure 5, the pump housing 112 may comprise a first portion 210 that is a substantially non-porous

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structure capable of providing the degree of gas impermeability and strength needed to fulfil its housing and load supporting functions and a second portion 212 that has a relatively greater porosity providing a relatively more open structure that defines a plurality of mini-passages that in combination define a lubricant return passage. Thus, a lubricant return passage may be defined by a region of relatively higher porosity surrounded by a substantially non-porous structure. Configuring a lubricant return passage as a porous zone within a substantially non-porous structure, may provide improved heat transfer as compared with an open channel. As shown in Figure 5, the second portion 212 of higher porosity that defines a lubricant return passage may be defined by a regular mesh-like or honeycomb structure, an amorphous structure or a combination of the two.

Still referring to Figure 5, although in some examples the or a lubricant return passage may comprise an open pipe-like structure dimensioned to provide a capillary effect, the or a lubricant return passage may instead comprise an outer portion defined by grooves 214 extending in the lengthways direction lubricant passage and an at least substantially uninterrupted passage disposed inwardly of the grooves 214. The capillary effect may then be provided by the grooved or porous portion of the lubricant return passage.

While not limited to these materials, the pump housing may be made of aluminium, aluminium alloy or stainless steel.

It will be understood that the provision of one or more lubricant return passages as disclosed herein allows the possibility of using a pump in any desired orientation, including a fully inverted orientation as shown in Figure 1, while allowing reliable return of lubricant from the rolling bearing to the lubricant reservoir for resupply to the bearing. As compared with systems in which lubricant return is by a wicking action obtained using rods made of an absorbent material, a significant space saving may be gained by having one or more lubricant return passages configured such that, in use, lubricant is able to move in an upwards direction against gravity by capillary action so that the presence of an absorbent material to provide the wicking action is not needed. This is an advantage as space economy within a pump housing is often important, assembly issues relating to ensuring the absorbent rods make a good contact with the lubricant reservoir are avoided and there

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is less fibrous material in the pump that might give rise to loose fibres that may pollute the lubrication system. There may also be advantages in terms of routing since lubricant return passages configured to move lubricant upwards by capillary forces are not restricted to running in straight lines.

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It will be understood that in the illustrated embodiments a lubricant supply system is configured to supply lubricant from a lubricant reservoir to a rolling bearing and return supplied lubricant that has passed downwardly through the rolling bearing to the lubricant reservoir via a lubricant return passage that extends upwardly past the rolling bearing. The
10 lubricant return passage is configured such that the lubricant is able to move upwards against gravity by capillary action without the presence of an absorbent wicking material or any other separate, non-integral, structure in the lubricant return passage to provide the capillary action. A lubricant return passage may be configured to enable upwards movement of lubricant against gravity by capillary action by one or more of suitable sizing
15 of the passage, forming grooves in a wall defining the passage or forming the passage as an integral porous structure within a non-porous body. By not having to provide a separate absorbent wicking material in the lubricant return passage and configuring the lubricant return passage so that the capillary action is provided by an integral feature of the passage, it is possible to obtain a more compact structure using relatively narrower passages, avoid
20 assembly tasks and avoid having a fibrous material in the lubricant passage that may shed fibres into the lubricant circulation path.

In the illustrated examples, the lubricant return system comprises lubricant collection channelling in which lubricant that has passed through the rolling bearing is received and
25 conducted to a location radially outwardly of the outer periphery of the rolling bearing. This is not essential. For example, the lubricant collection channelling may be disposed entirely inwardly of the outer periphery of the rolling bearing and the one or more lubricant return passages may have an upstream end portion connected to such channelling and be configured to convey the lubricant generally radially outwardly with respect to the rolling
30 bearing before turning in the general direction of the lubricant reservoir.

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The lubricant return passage, or passages, may comprise two or more generally straight portions joined by a bend portion. The lubricant return passage, or passages, may include arcuate portions and in some examples, may comprise a combination of arcuate and straight portions or arcuate, bend and straight portions as may be desirable for routing purposes.

5

In the illustrated examples, the lubricant return passages are planar in their direction of travel towards the lubricant reservoir. Thus, in the examples shown in Figures 3 and 4, while the lubricant return passages may extend parallel to, or at least in part converge on, the axis of rotation of the rotor shaft, they are disposed in a single vertical (as viewed in
10 Figures 3 and 4) plane that contains the axis of rotation of the rotor shaft. It is to be understood that this is not essential. The lubricant return system may comprise one or more lubricant return passages that are at least in part non-planar in their direction of travel towards the lubricant reservoir. Thus, at least a portion of a lubricant return passage may be spaced from and wind with respect to the axis of rotation of the rotor shaft so that, for
15 example, one or more lubricant return passages may comprise helical, spiralling or otherwise arcuate portions that extend through several planes that are vertical (as viewed in Figures 3 and 4) and contain the axis of rotation.

It will be understood that in examples in which the rotor shaft is supported by two bearings
20 that are disposed adjacent one another so that the rotor blades are supported cantilever-style, each bearing may be a rolling bearing lubricated in analogous fashion of the rolling bearings shown in Figures 3 and 4 with a lubricant return system to collect lubricant that has passed through the rolling bearings that comprises lubricant return passages to return the collected lubricant to a lubricant reservoir, or reservoirs, by capillary action.

25

The lubricant may comprise any lubricant suitable for lubricating bearings under the conditions applying in a pump and sufficiently liquid to allow it to be returned to the lubricant reservoir via a lubricant return passage by capillary action. The lubricant may comprise an organic or synthetic oil.

30

It is to be understood that although the lubricant return system shown in the drawings is described primarily in connection with a turbomolecular pump, it or a lubricant return

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system employing the same or a similar capillary passage lubricant return system may be applied to returning lubricant for resupply in other forms of pump, for example, screw or scroll pumps.

CLAIMS

1. A pump comprising:
 - a pump housing;
 - 5 a pumping mechanism disposed in said pump housing, said pumping mechanism comprising a rotor shaft having an axis of rotation;
 - a plurality of bearings supporting said rotor shaft for rotation relative to said pump housing, said plurality of bearings including a rolling bearing having an outer periphery, a first major side disposed in a first plane that extends transverse to said axis of rotation and
 - 10 a second major side disposed in a second plane that is spaced from said first plane and extends transverse to said axis of rotation;
 - a lubricant supply system; and
 - a lubricant transfer device provided on said rotor shaft to transfer lubricant from said lubricant supply system to said first major side of said rolling bearing,
 - 15 wherein said lubricant supply system comprises a lubricant reservoir and a lubricant return system by which lubricant that exits said rolling bearing at said second major side is returned to said lubricant reservoir, and
 - wherein said lubricant return system comprises a lubricant return passage that has an upstream end and extends from said upstream end past said outer periphery and through
 - 20 said first plane and is configured such that, in use, lubricant is able to move in an upwards direction in said lubricant return passage by capillary action.
2. A pump as claimed in claim 1, wherein said lubricant return passage extends alongside and spaced apart from said axis of rotation so as to be disposed radially outwardly
- 25 of said outer periphery at least when passing said outer periphery.
3. A pump as claimed in claim 1 or 2, wherein said outer periphery is disposed a first radial distance from said axis of rotation, said upstream end is disposed a second radial distance from said axis of rotation and said second radial distance is greater than said first
- 30 radial distance.

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4. A pump as claimed in claim 1, 2 or 3, wherein said lubricant return passage has a downstream end that discharges into said lubricant reservoir.

5. A pump as claimed in claim 4, wherein said downstream end is covered by said
5 lubricant reservoir.

6. A pump as claimed in any one of the preceding claims, wherein said upstream end of said lubricant return passage is disposed in a third plane that extends transverse to said axis of rotation and said second plane is disposed intermediate said first and third planes.

10

7. A pump as claimed in any one of the preceding claims, wherein said lubricant return system comprises lubricant collection channelling configured to receive said lubricant that exits said rolling bearing at said second major side and said upstream end of said lubricant return passage is connected with said lubricant collection channelling to receive lubricant
15 from said lubricant collection channelling.

8. A pump as claimed in any one of the preceding claims, wherein the lubricant reservoir has a surface that is disposed closest to said rolling bearing and said first and second planes are disposed intermediate said surface and said upstream end of the lubricant
20 return passage.

9. A pump as claimed in any one of the preceding claims, wherein said lubricant return passage is defined by:

- 25
- i) said pump housing; or
 - ii) a holder that holds at least one of said lubricant reservoir and said rolling bearing and is fitted in said pump housing.

10. A pump as claimed in claim 9, wherein said pump housing or said holder comprises a first portion that is non-porous and at least one second portion having that is porous, said
30 at least one second portion defining at least a portion of said lubricant return passage.

- 20 -

11. A pump as claimed in any one of claims 1 to 9, wherein said lubricant return passage is configured such that, in use, lubricant is able to move in an upwards direction in said lubricant return passage by capillary action by at least one of:

- i) having a relatively narrow cross-section; and
- 5 ii) having grooves extending along said lubricant passage provided in a wall defining said lubricant return passage.

12. A pump as claimed in any one of the preceding claims, wherein in a direction of travel from said upstream end towards said lubricant reservoir, said lubricant return passage
10 is disposed in a single plane that contains said axis of rotation.

13. A pump as claimed in any one of claims 1 to 11, wherein at least a portion of said lubricant return passage is spaced from and winds with respect to said axis of rotation.

15 14. A pump as claimed in any one of the preceding claims, wherein said lubricant return system comprises a plurality of said lubricant return passages and said passages have respective cross-section areas that are different sizes whereby, in use, as the respective cross-section areas change due to thermal expansion and contraction as temperature conditions in said pump change different said lubricant return passages become active to
20 move said lubricant in said upwards direction by said capillary action.

15. A method of manufacturing a pump comprising a pump housing, a pumping mechanism that includes a rotor shaft supported by a plurality of bearings that includes a rolling bearing and a lubricant reservoir for a supply of lubricant to lubricate said rolling
25 bearing, said method comprising:

providing a seat for said rolling bearing; and

providing a lubricant return passage via which lubricant that in use passes through the rolling bearing is returned to said lubricant reservoir,

wherein said lubricant return passage has an upstream end and extends past an outer
30 periphery of said rolling bearing to said lubricant reservoir and is configured such that, in use, lubricant at said upstream end is able to move in an upwards direction in said lubricant return passage by capillary action, and

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wherein at least a part of said vacuum pump in which said lubricant passage is defined is formed by a generative production process.

16. A method as claimed in claim 15, further comprising providing lubricant collection
5 channelling to receive said lubricant that passes through the rolling bearing and channel said lubricant in a lateral direction with respect to said rotor shaft to said upstream end.

17. A method as claimed in claim 15 or 16, said part comprises a first portion that is non-porous and at least one second portion having that is porous, said at least one second
10 portion defining at least a portion of said lubricant return passage.

18. A method as claimed in claim 15, 16 or 17, wherein at least a portion of said lubricant return passage is configured to provide said capillary action by at least one of:
i) having a relatively narrow cross-section area; and
15 ii) having grooves extending along said lubricant return passage provided in a wall defining said lubricant return passage.

19. A method as claimed in any one of claims 15 to 18, wherein said part in which said lubricant return passage is defined is a part of said pump housing.
20

20. A method as claimed in any one of claims 15 to 18, wherein said vacuum pump comprises a removable holder to hold at least one of said rolling bearing and said lubricant reservoir and said holder is said part in which said lubricant passage is defined.

21. A method as claimed in any one of claims 15 to 20, wherein said outer periphery is disposed a first radial distance from an axis of rotation defined by said rotor shaft, said upstream end is disposed a second radial distance from said axis of rotation and said second radial distance is greater than said first radial distance.
25

22. A method as claimed in any one of claims 15 to 21, wherein said rolling bearing comprises a first major side disposed in a first plane that extends transverse to said rotor shaft, a second major side spaced from said first side and disposed in a second plane that
30

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extends transverse to said rotor shaft and said lubricant return passage extends from said upstream end through said first plane and said second plane to said lubricant reservoir.

23. A method as claimed in any one of claims 15 to 22, further comprising providing a plurality of said lubricant passages and providing said plurality of lubricant passages with respective different cross-section areas whereby, in use, as the respective cross-section areas change due to thermal expansion and contraction as temperature conditions in said pump change different said lubricant return passages become active to move said lubricant in said upwards direction by said capillary action.

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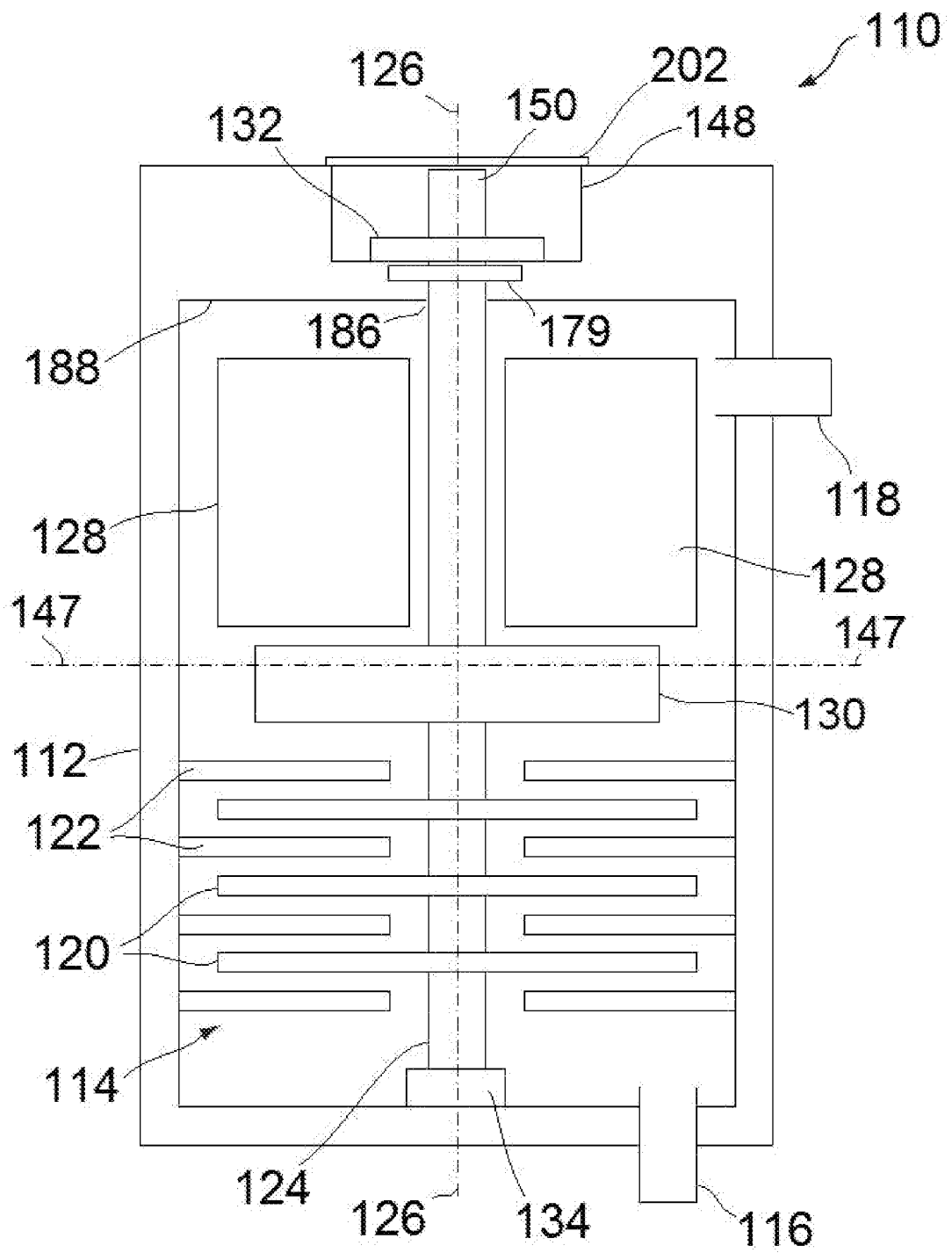


FIG 1

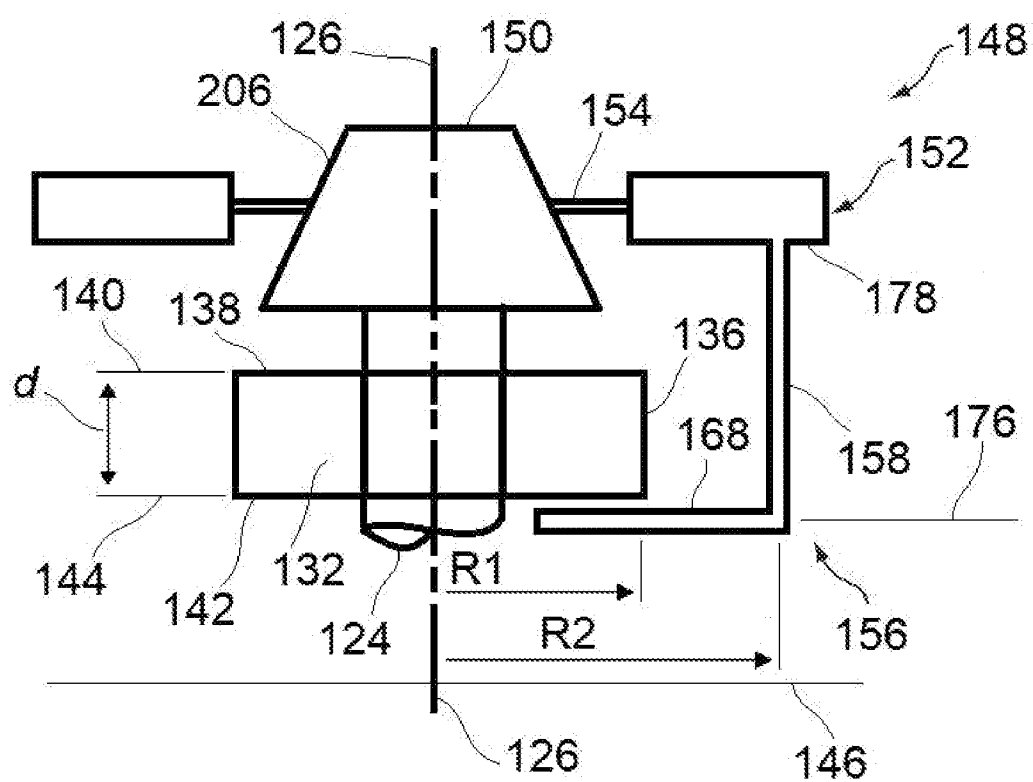


FIG 2

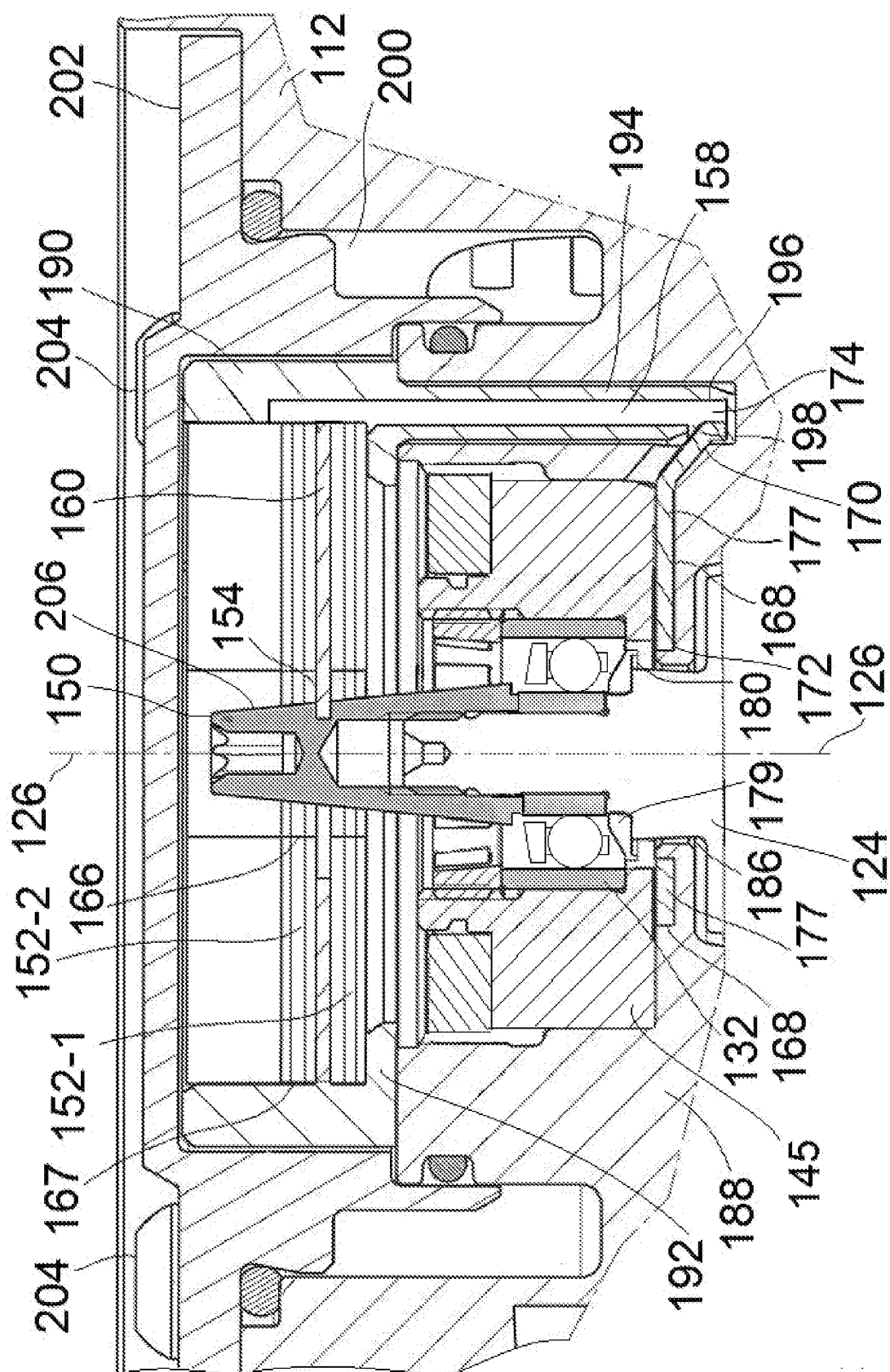
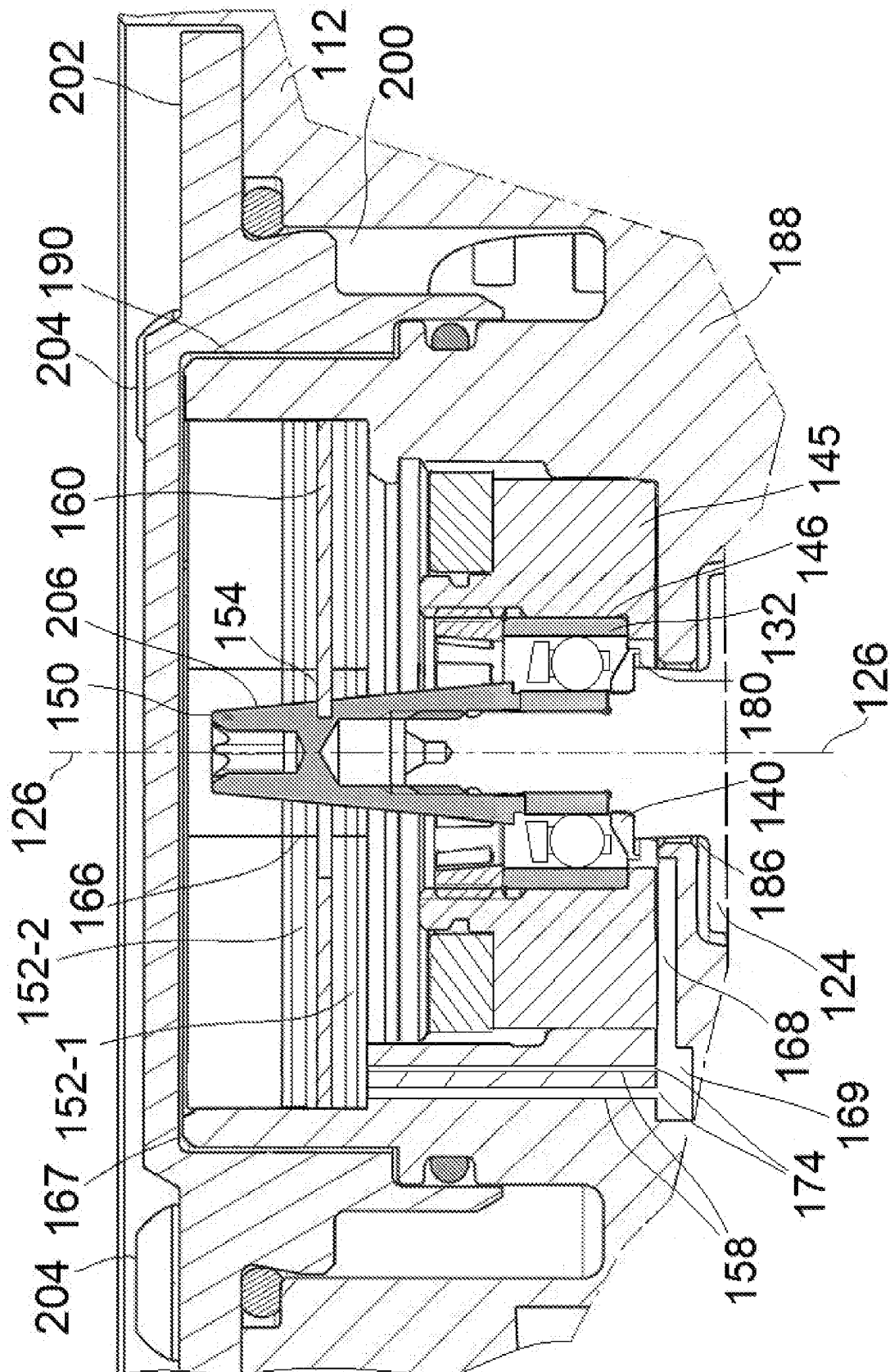


FIG 3



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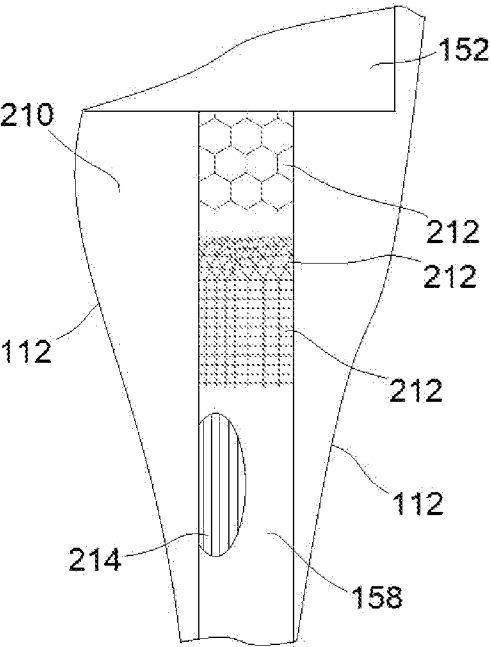


FIG 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/051642

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04D19/04 F04D29/063 F04D29/059
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2011 109929 A1 (PFEIFFER VACUUM GMBH [DE]) 14 February 2013 (2013-02-14)	1-14
Y	abstract paragraph [0009] - paragraph [0031] figures	15-23

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Y	abstract	15-22
A	page 5, line 20 - page 6, line 6 page 12, line 15 - line 23 figures 1,8	14,23

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Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search

6 September 2019

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/051642

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	abstract paragraph [0006] - paragraph [0051] figures -----	1-14

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